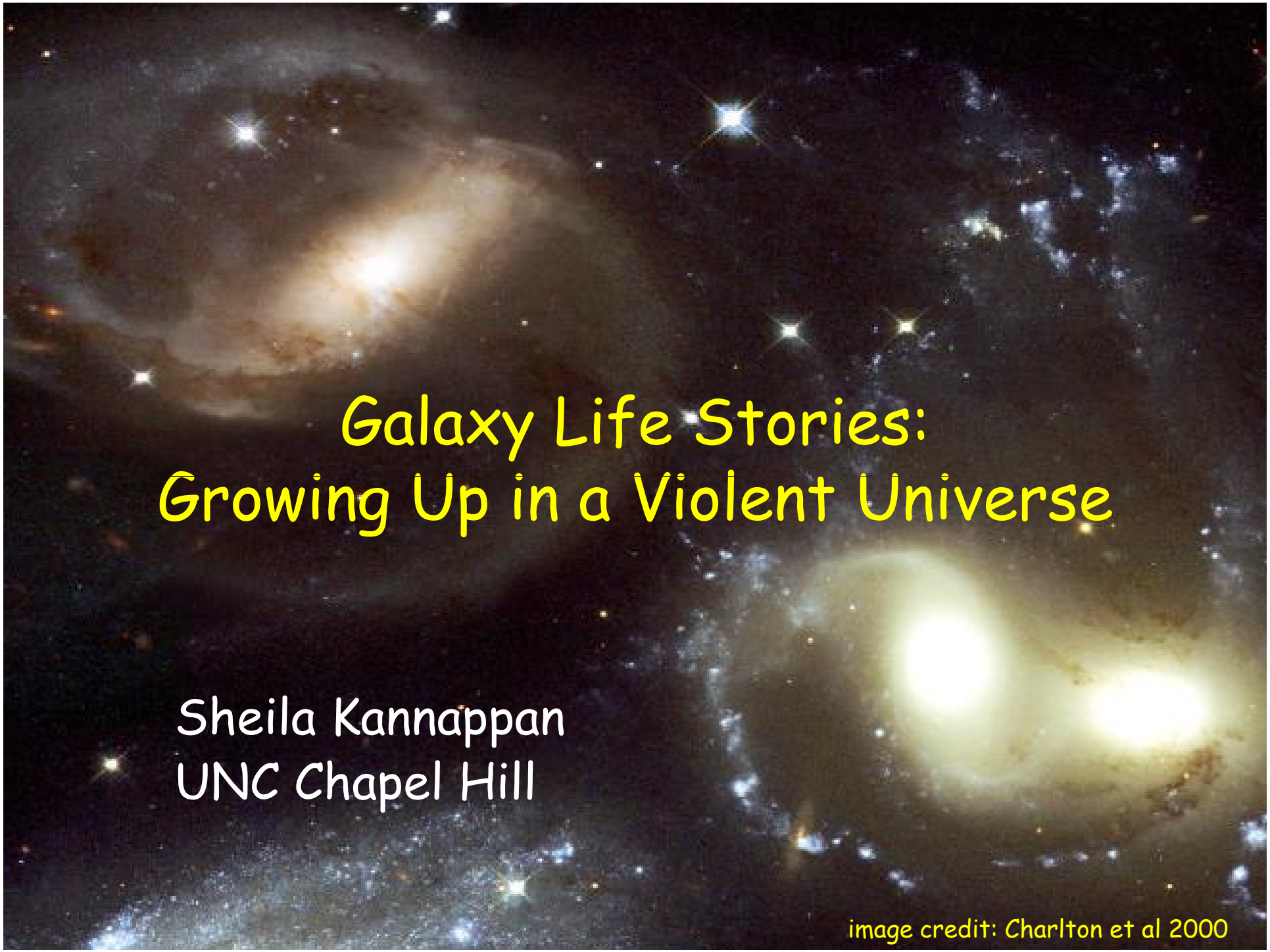


Galaxy Life Stories: Growing Up in a Violent Universe

Sheila Kannappan
UNC Chapel Hill

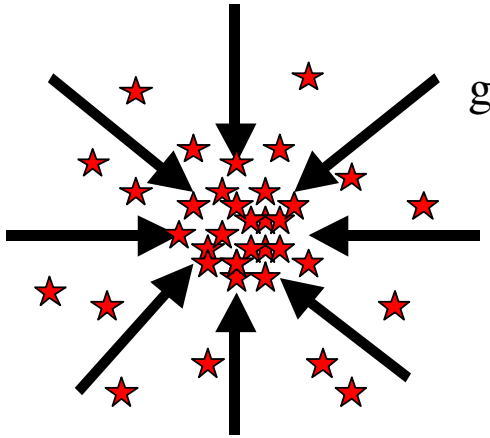
image credit: Charlton et al 2000

Outline

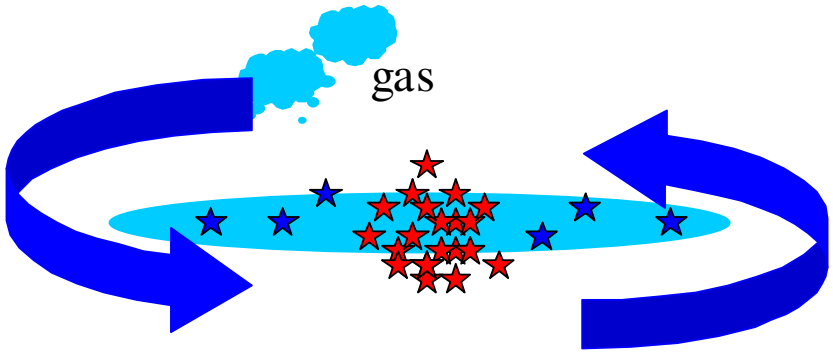
- Isolated Galaxy Evolution
- Galaxy Collisions
- Hierarchical Galaxy Evolution
- The Puzzle of Disk Regrowth

Isolated Galaxy Formation

1. first stars form bulge



2. gas forms disk



Hubble Sequence of Galaxy Types: Clue to Arrow of Evolution?

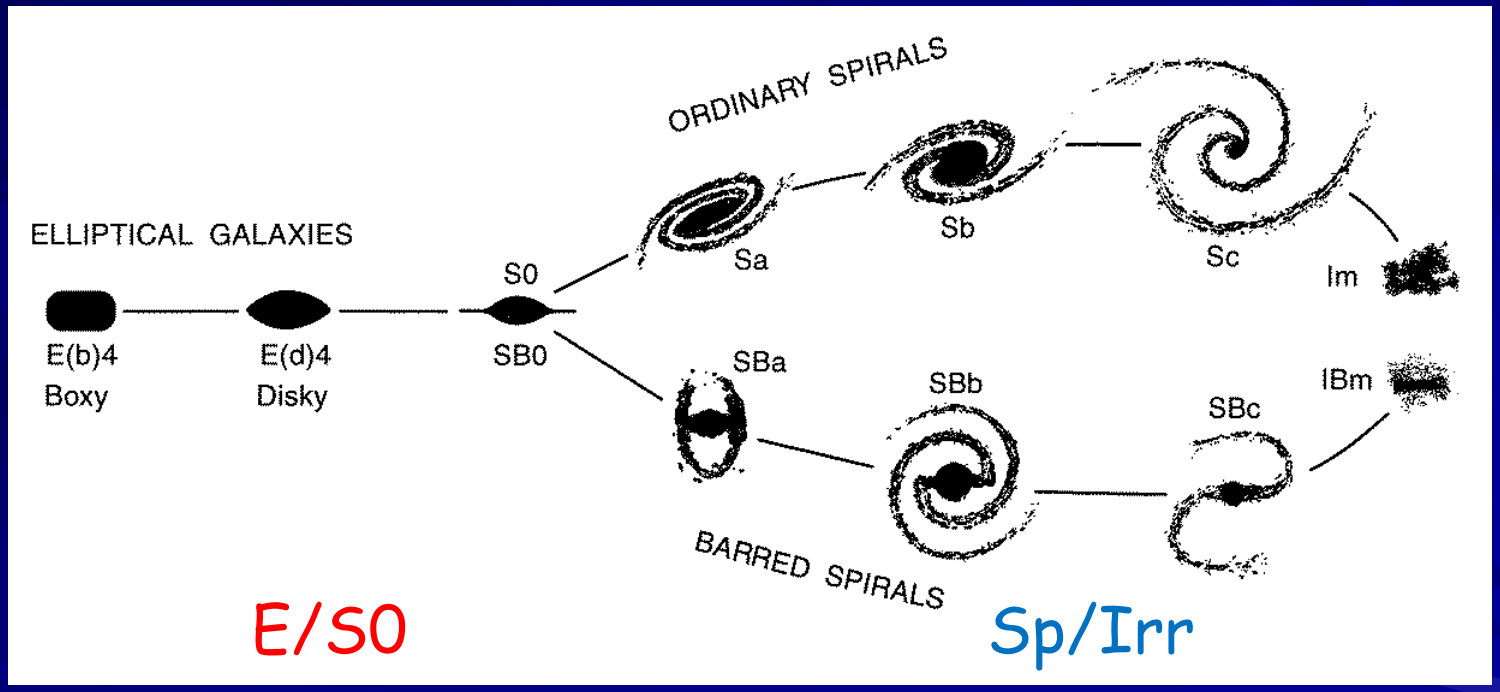


figure: Kormendy & Bender 1996

gas infall and disk growth

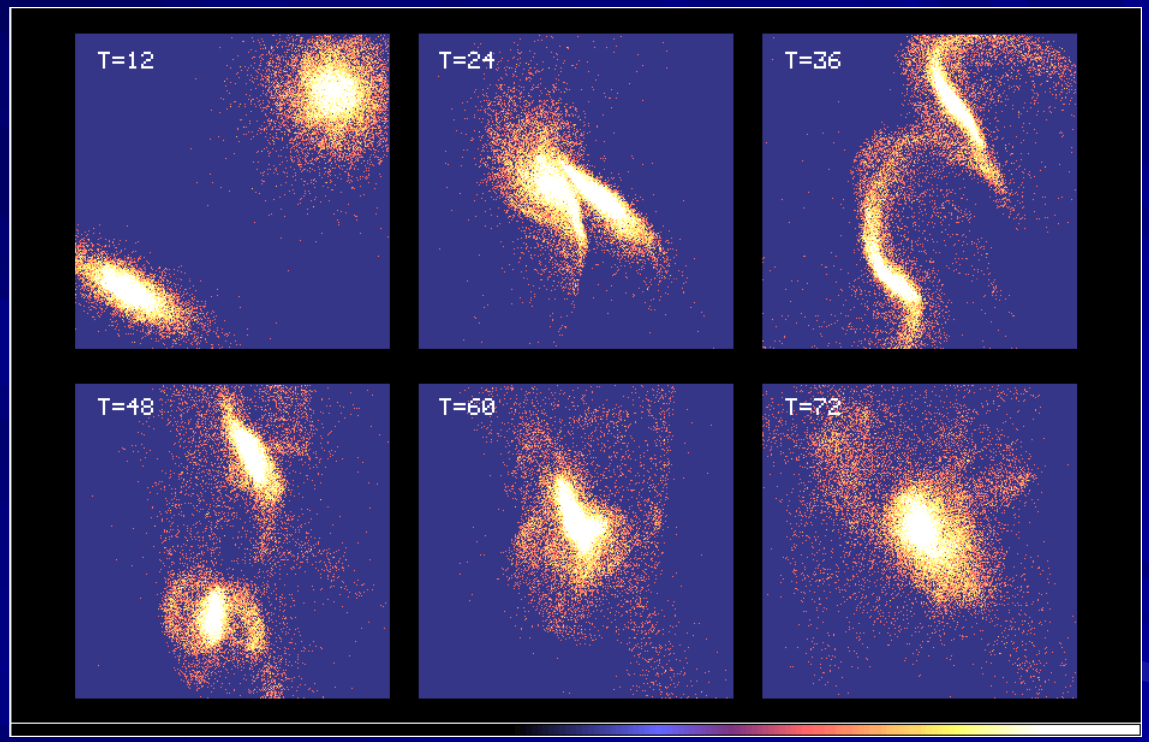

But...
For their size, galaxies are about a million times closer together than stars are.
Perseus Cluster, Digitized Sky Survey, Royal Obs. of Edinburgh

What happens when galaxies collide?

Stars pass between each other and tug each other out of disk rotation

1. stars move in all directions

2. spheroids develop (bulges, elliptical galaxies)



Computer simulation without gas, C. Mihos 1999

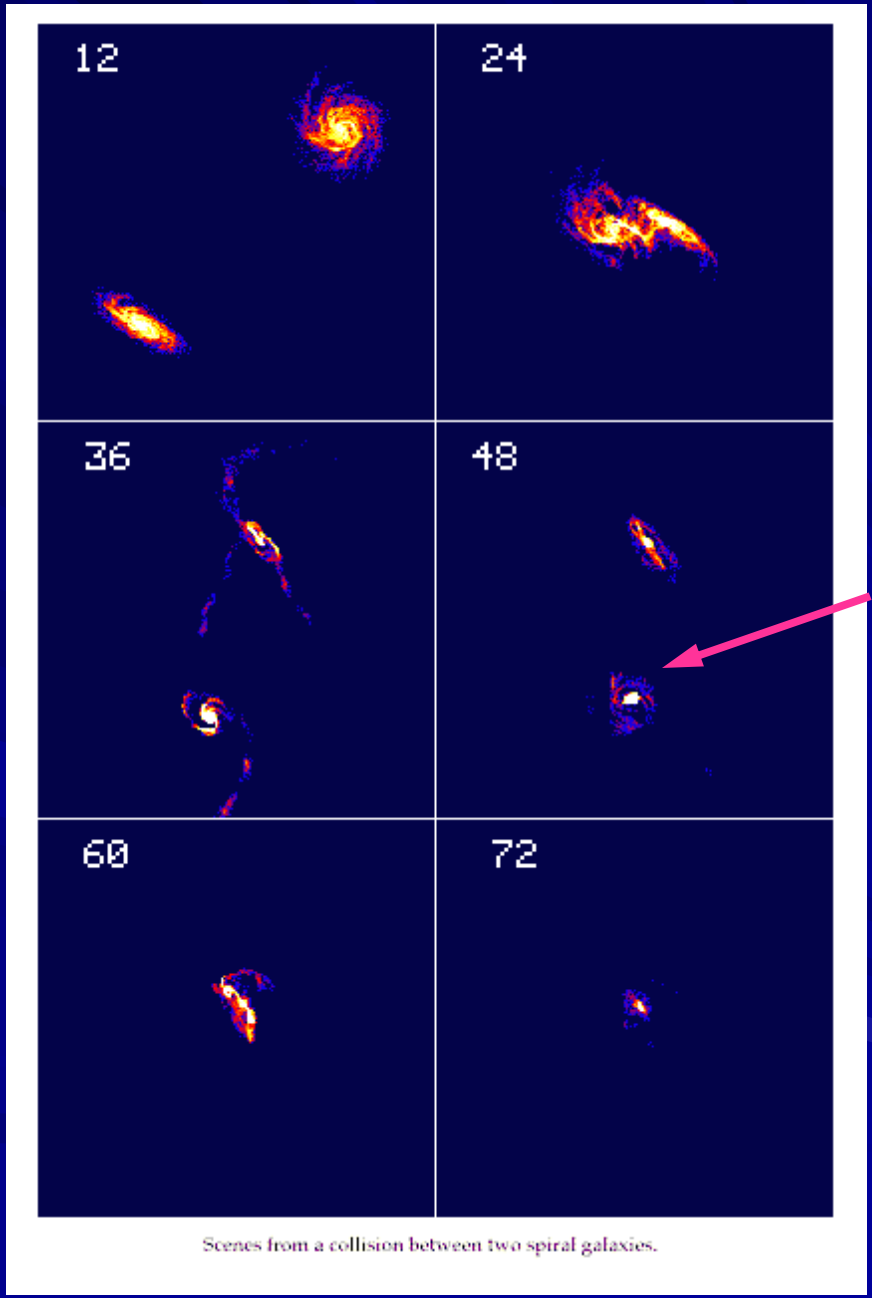
meanwhile...

Gas flows inward

1. new stars form in a huge burst

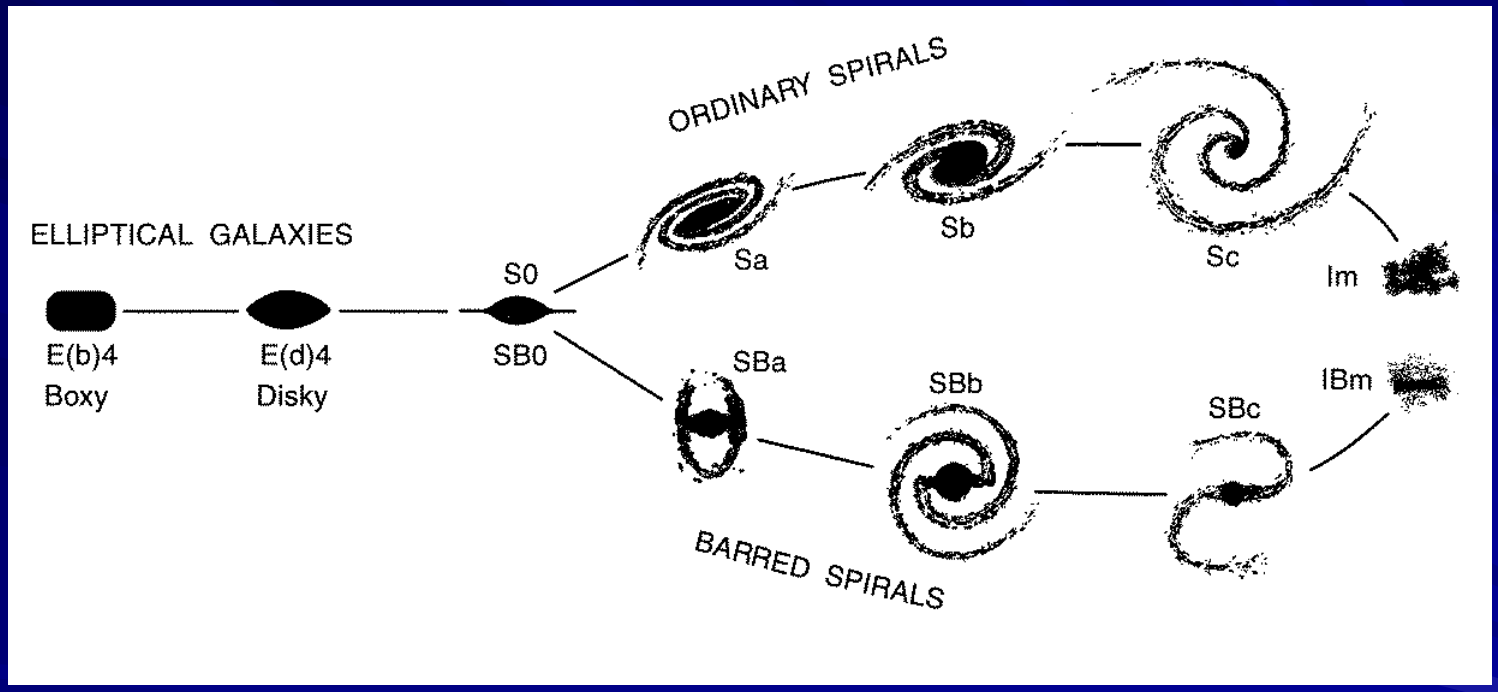
2. central concentration grows (bulge!)

Simulation with gas and stars; colorscale shows intensity of star formation (Mihos 1999)



Scenes from a collision between two spiral galaxies.

Hubble Sequence of Galaxy Types: Arrows Both Ways!

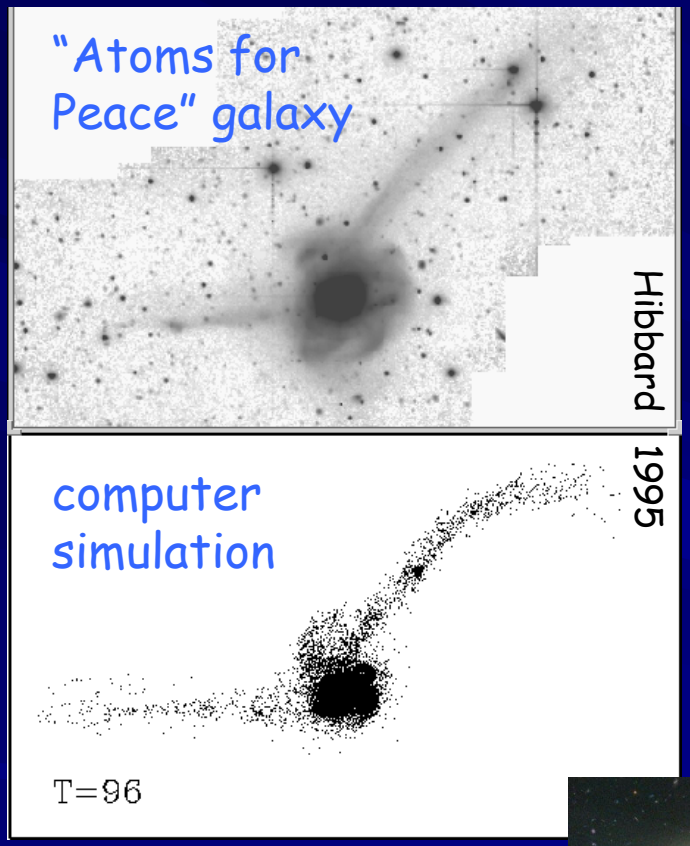


gas infall and disk growth

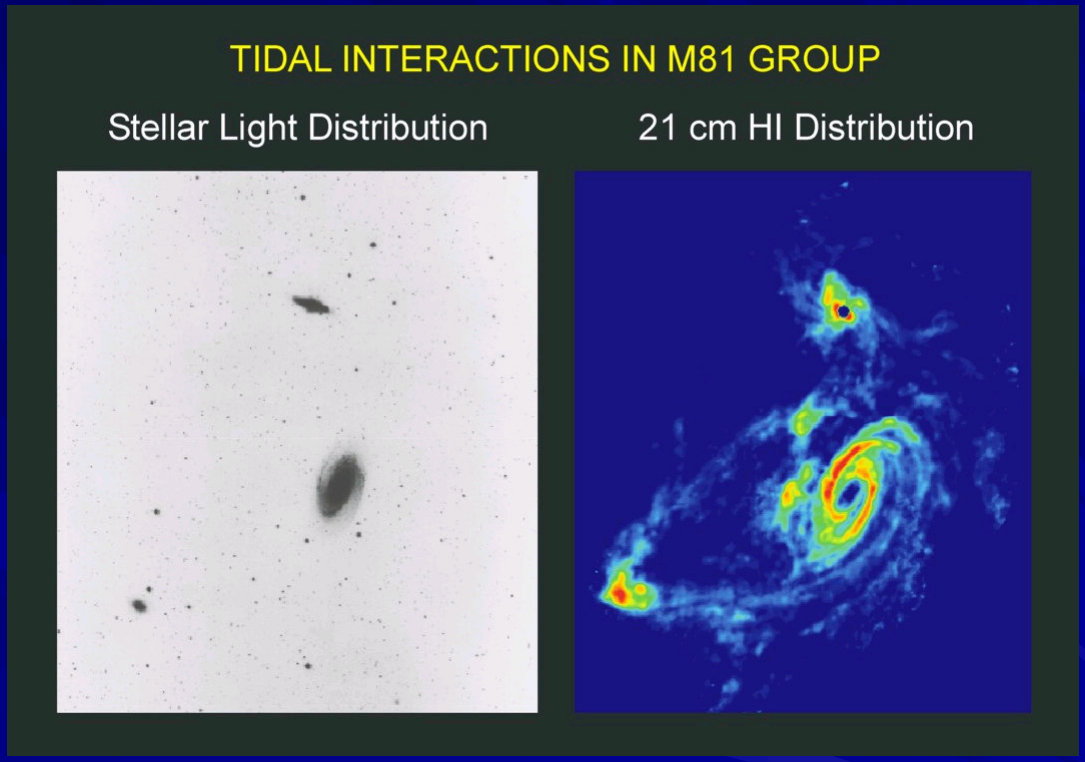
galaxy mergers & interactions

Evidence for galaxy mergers

"peculiar" galaxies = remnants



"invisible" interactions revealed in gas



NRAO/AUI: Yun, Ho, Lo

Evidence for galaxy mergers

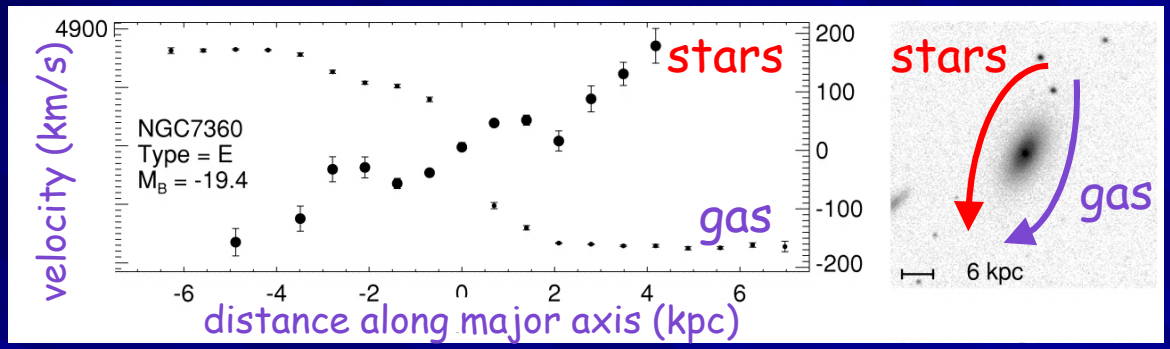
Looking back in time…

Distant galaxies in the Hubble Ultra Deep Field

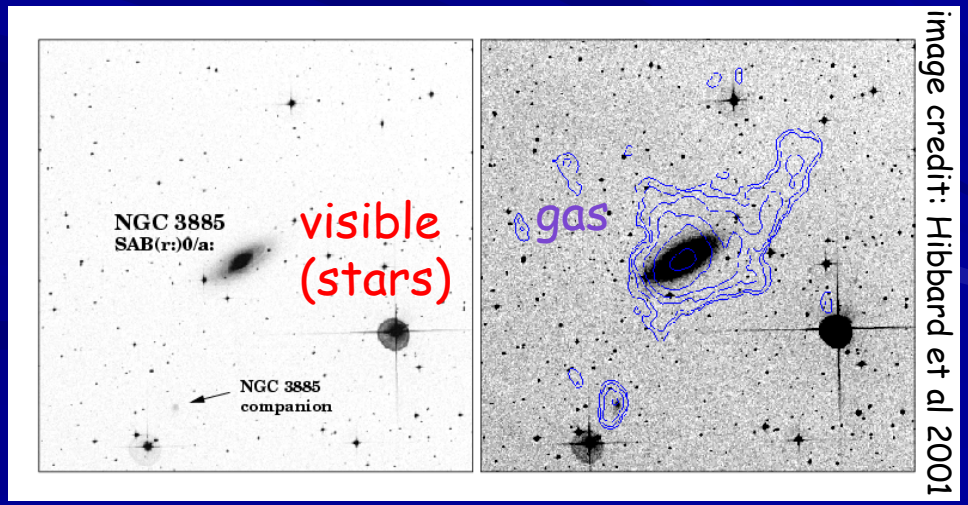
Evidence for galaxy mergers

My own research:

- Galaxies with round/thick Hubble types show an unusually high frequency of counterrotating gas and stars
  (Kannappan & Fabricant 2001)



- Galaxies with actively growing bulges show a high frequency of small companions and peculiarities
  (Kannappan, Jansen, & Barton 2004)



"Hierarchical" Galaxy Formation

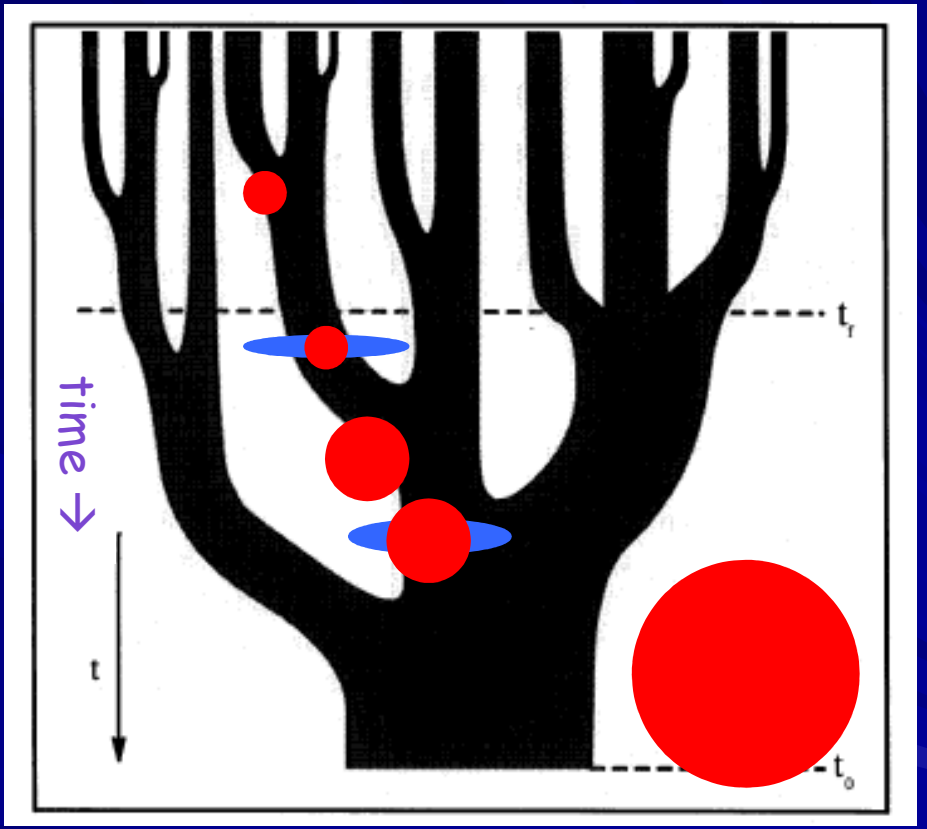
small things

merge into

bigger things

which merge into

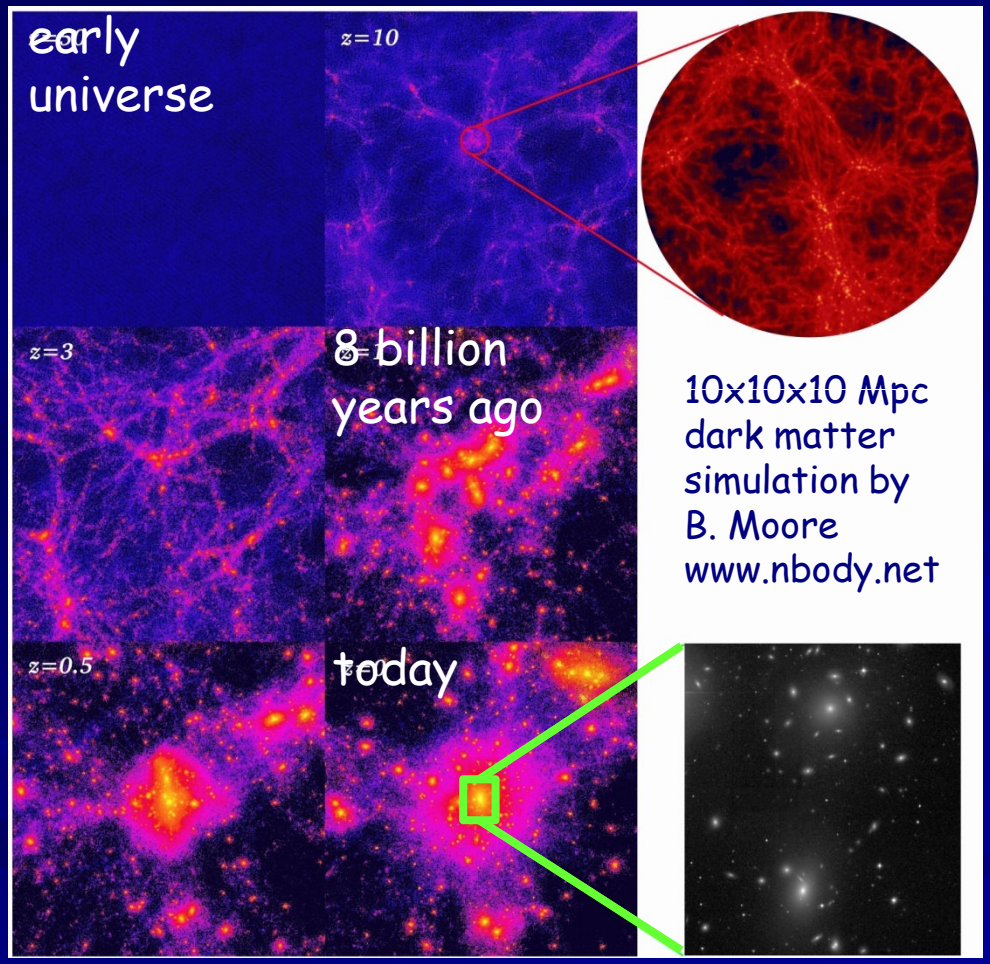
bigger things…



Lacey & Cole 1993

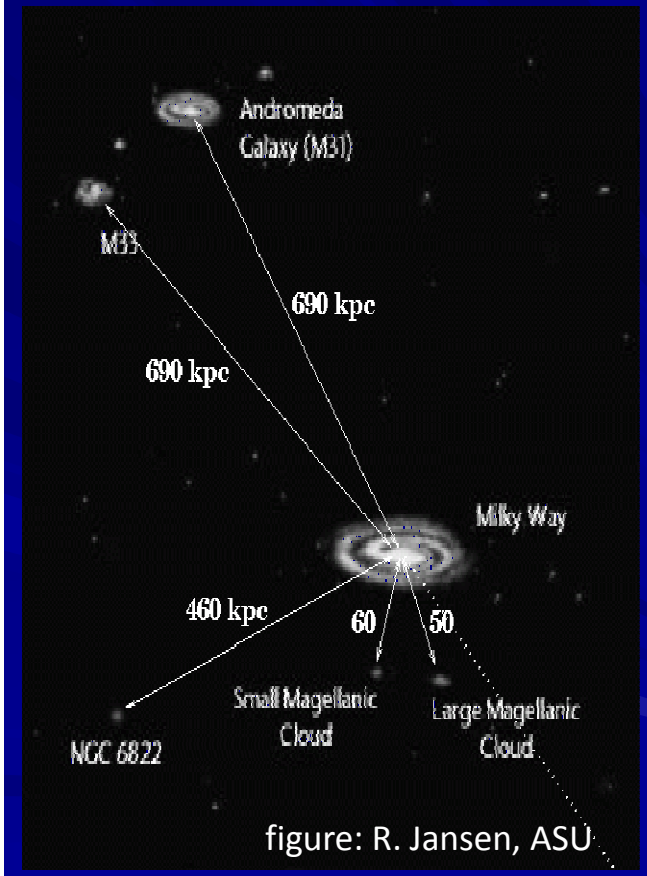
alternating spheroid & disk growth

What this looks like



10x10x10 Mpc dark matter simulation by B. Moore www.nbody.net

Similar to our Local Group?

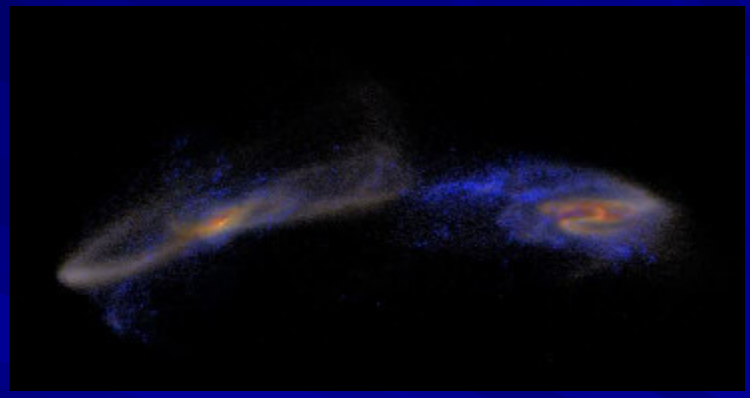


luminous matter inside "halo"

What is the "normal matter" doing?

Two theoretical simulations:

From L. Mayer:
Gas – green
New stars – blue-white
Old stars – yellow-red



From P. Jonsson & T. Cox:
Gas – green
New stars – blue-white
Old stars – yellow-red

Do spheroids really regrow disks? Do disks truly contain spheroids?

HST:"Evil Eye Galaxy"

Dalcanton+04

pseudo bulges:

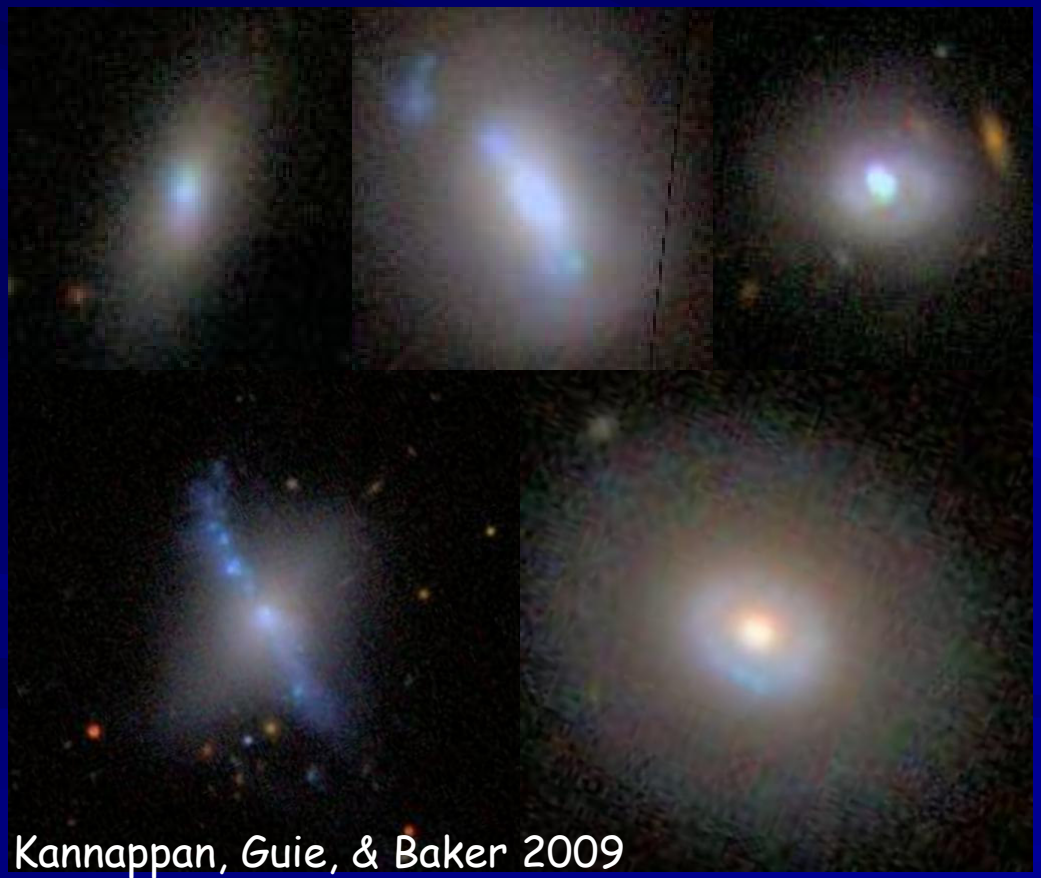
- are inner disks
- are young
- are common (we have one!)

Why are galaxies like our own so ubiquitous in a violent Universe?

Hot off the presses!

Smoking gun evidence of disk regrowth in E/S0s

...and pseudobulges too!



Kannappan, Guie, & Baker 2009

We have identified a large population of E/S0 galaxies with the blue colors of spiral galaxies of the same mass. *Blue means new.*

They are blue in their centers *and* in their outer disks.

FAQ about blue E/S0s

Q: What's the evidence for disk regrowth?

A: Statistical excess of blue outer disks and secondary stellar disks; larger radii and more rotation than "red and dead" E/S0s.

Q: Couldn't they be dying merger remnants?

A: The rare high-mass cases probably are. But the lower mass ones are too common, have too much gas, and aren't disturbed enough.

Q: How fast are they growing?

A: As fast as spiral galaxies.

Q: Why did we miss them until now?

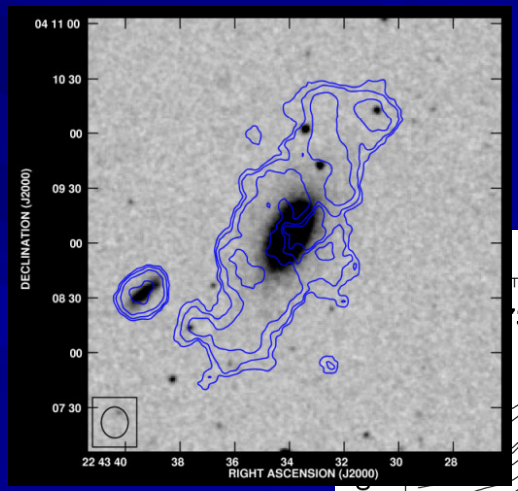
A: They have mostly low masses.

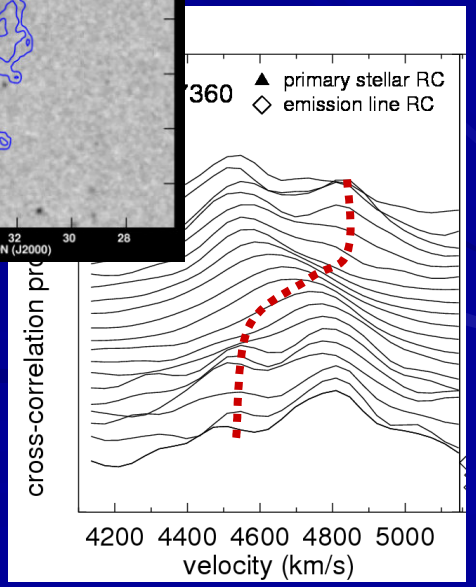
Q: How common are they?

A: At the Milky Way's mass, ~5% of E/S0s today but possibly >20% at the time of the Milky Way's "last major merger" ~8 billion years ago.

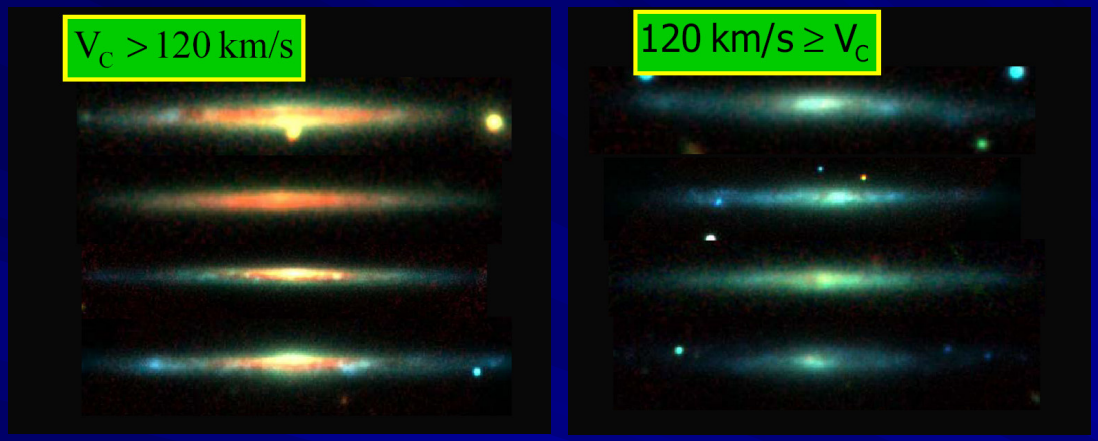
Q: What's next?

A: Better data on E/S0 regrowth potential; extension to earlier epochs.





Not so FAQ: how do low masses fit in?



Dalcanton et al. 2004)

- pseudobulges most common at low masses
- threshold mass for gas richness
- clustering
- "downsizing" → today's low mass galaxies behave like higher mass galaxies at earlier times

The Proposal

Disks regrow around spheroids when gas is available

below threshold mass and in non-cluster environments

Pseudobulges may subsume smaller spheroidal bulges

already seen – composite spheroidal+pseudobulges detected in S0s with HST (Erwin et al 2007)

S0 formation may enable the dwarf → giant transition

change in star formation efficiency & presence of bulge

What's in our future?

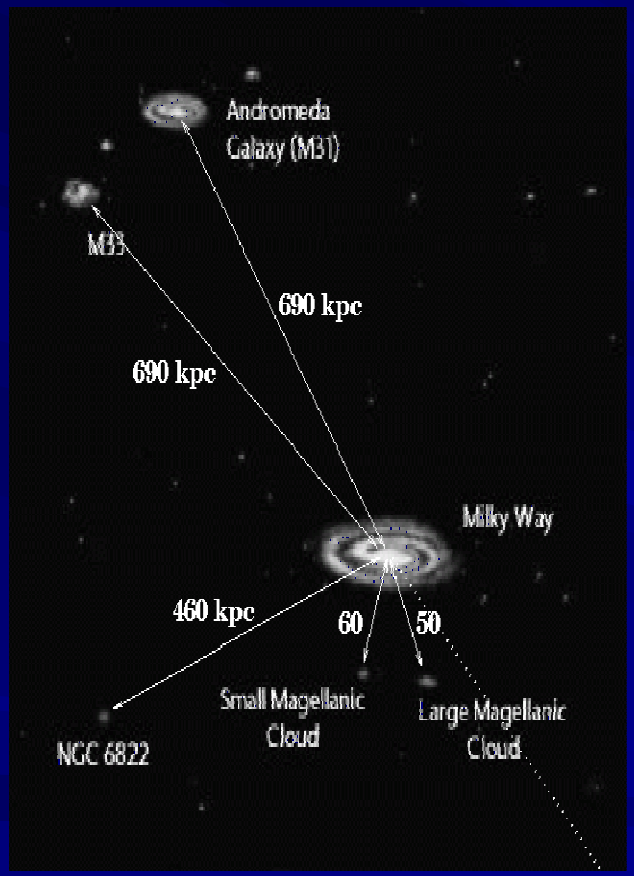
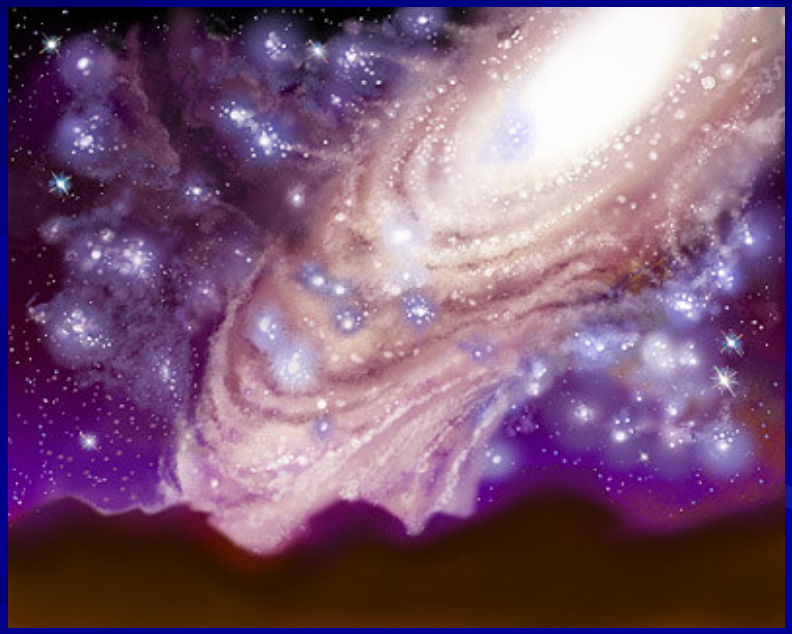


figure: R. Jansen, ASU

Collision with Andromeda Galaxy seen from Earth



artist's conception: Gitlin, STScI

Things to Remember

- Galaxies evolve along the Hubble sequence both ways (← rounder by merging, → diskier by gas accretion)
- The puzzling abundance of galaxies like our own may be explained by evidence for disk (and pseudobulge) regrowth after mergers
- The Milky Way & Andromeda will merge in about 5 billion years, perhaps finally creating a "red and dead" E/S0 galaxy